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Applications of Marine Geodesy

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This paper is a summary of a 1980 research study initiated by the Marine Technology Society and several U.S. government agencies to identify requirements for marine geodetic applications in support of national objectives in ocean science, engineering, and operations over the next two decades. The study established a broad definition of marine geodesy to form a base for marine geodesy's several maritime applications. The study investigated the following areas: bathymetry, hydrography, marine gravity and geophysics, positioning and navigation, plate tectonics/seafloor spreading, ocean surface topography, mean sea level, and tsunamis.

Introduction

Several national studies have indicated in a qualitative way that marine positioning and navigation capabilities are not satisfactory and require improvement. A quantitative analysis of the problem was, however, still lacking. To address the problem, the Marine Geodesy Committee of the Marine Technology Society (MTS), together with several interested federal agencies, held a planning meeting on August 16, 1977, to pursue the concept of a marine geodesy study. It was attended by representatives of the Defense Mapping Agency (DMA), MTS, the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration's (NOAA) National Geodetic Survey and Office of Ocean Engineering, the Office of Naval Research (ONR), the Office of the Oceanographer of the Navy, and the U.S. Coast Guard (USCG). During the course of this and subsequent meetings, the following definition of the term marine geodesy and its areas was established for this study [*Saxena*, 1980]:

> Marine geodesy is the science which defines and establishes control points in and/or on the ocean, and the shape of the ocean including its floor. It includes those maritime activities that depend on determination of position or accurate measurements on, under, and above the ocean surface. The areas covered under this interdisciplinary field, among others, include: bathymetry, positioning (ocean floor and surface), gravity, plate tectonics, seafloor spreading, geoidal undulation, tsunami research, mean sea level, and tidal variation.

Study Objectives

The following study objectives were established: (1) Identify requirements for applications of marine geodesy over the next two decades. (2) Identify any deficiencies in our current technical abilities to meet these requirements. (3) Propose areas of research and development (R&D) to eliminate identified deficiencies. (4) Evaluate the ability of ongoing programs in marine geodesy to handle proposed R&D efforts. (5) Produce a comprehensive report for open distribution as a basis for program development.

The study was conducted in three phases: (1) State-of-the-art papers were prepared by DMA, the U.S. Maritime Administration (MARAD), NOAA, and USCG. Several technical publications were submitted by NASA in lieu of the state-of-the-art paper. (2) Requirement statements were prepared by the study panel and the marine industry. (3) The state-of-the-art and requirement papers were discussed at a 2-day meeting held January 10–11, 1980.

Study Panel

The study panel and their areas of expertise were as follows:

Narendra Saxena, University of Hawaii at Manoa, Chairman (Positioning and Navigation)

Harold Black, APL/Johns Hopkins University (Space Instrumentation)

Carl Bowin, Woods Hole Oceanographic Institution (Marine Gravity, Geophysics, Geology)

Myrl C. Hendershott, Scripps Institution of Oceanography (Ocean Surface Topography, Mean Sea Level, Tidal Variations)

A. George Mourad, Battelle Columbus Laboratories (Economic Aspects)

T. S. Murty, Institute of Ocean Sciences, Sidney, B.C. (Tsunamis)

Fabian C. Polcyn, ERIM/University of Michigan (Shallow Water Hydrography)

Fred Noel Spiess, Scripps Institution of Oceanography (Plate Tectonics, Seafloor Spreading)

Phillip Stutes, John E. Chance Co., Lafayette, La. (Oil and Gas)

Marie Tharp, Oceanographic Cartographer, Piedmont, N.Y. (Bathymetry, Differential Bathymetry (Deep Water))

George A. Zahn, Deep Sea Ventures, Inc. (Ocean Mining)

Narendra Saxena *has been editor-in-chief since 1976 of* Marine Geodesy *and is a founding member of the Tsunami Society. He is the cochairman of the Pacific Congress on Marine Technology to be held in Honolulu April 24–27, 1984. His research activities include satellite geodesy, ocean surveys and mapping, and remote sensing.*

Recommendations

Marine Gravity, Geophysics, and Geology

It has been estimated that where GEOS-3 altimetry is available, the accuracy of the gravity field in the wavelength range of about 200 km can be determined to about 8 mgal. However, to contribute significantly to knowledge of the thickness of oceanic lithosphere, the formation of topographic features, asthenospheric convection, and compositional heterogeneity in the lithosphere and asthenosphere a minimum accuracy of 2 to 5 mgal and resolution of 100 to 1000 km is required.

The present solid-earth geophysical interpretation of the radar-altimeter measurements from satellites is hindered by the lack of detailed knowledge of the depth of the ocean floor over most of the Pacific and southern oceans. The most advanced measurement, that of the direct observation of the geoid, now needs the measurement of ocean depth.

To meet the requirements for the next two decades, the following recommendations are made:

1. Acquire improved accuracies worldwide for (a) satellite orbit determinations; (b) dynamic vehicle position measurements (and continuous); (c) radar altimeter measurements; and (d) satellite-satellite gravity measurements.
2. Launch polar orbiting radar altimeter and gravity missions to improve coverage at high latitudes.
3. Obtain strain measurements in oceanic regions by benchmark monitoring, by implanting instrumentation on the seafloor, and by measurements in Deep Sea Drilling Project drill holes.
4. Encourage ancillary programs for obtaining high quality data for bathymetry, topography, structure from seismic reflection and refraction, heat flow, magnetic field, and surface deformation from leveling and triangulation networks.
5. Encourage geological studies of critical and poorly known regions.

Bathymetry, Differential Bathymetry (Deep Ocean)

Two potential systems of obtaining bathymetric information are multibeam bathymetric sonar and sidescan (or side-looking) sonar. The former system provides quantitative information; the latter provides qualitative information.

The first nonmilitary version of a multibeam (wide swath) bathymetric sonar system—called SEA BEAM—has been in service since May 1977. Due to its angular resolution of 2.7°, swath width approximately equal to 78% of the depth, and maximum operating depth of 11,000 m, SEA BEAM may become the deep-water bathymetric system. Initial tests indicate an accuracy of ±2 m in water depths of 4750 m. Further testing of SEA BEAM is needed.

Although sidescan sonar provides basically a qualitative picture, it can also measure depth by using an appropriate mathematical model, i.e., using stereoscopic sidescan sonar images. Swath Map, a new sidescan sonar system, should be tested for accuracy of depth obtained from mathematical modeling of stereoscopic sonar images.

A precise differential bathymetric survey (±1 m) in the tsunamigenic earthquake area must be conducted for computing the tsunami energy based on an estimation of the elevation of the ocean bottom before and immediately after the earthquake.

To prepare for future marine mining needs, mapping and sampling of economic areas such as manganese nodule deposits must be extended.

To prepare for year-round commercial submarine tanker oil transport from the Arctic, under-ice bathymetry is needed over the routes from Prudhoe Bay under the ice cap to the U.S. east coast to provide a series of good quality (±10 m) strip charts.

Shallow-Water Hydrography

To facilitate greater offshore exploration activities, improved bathymetry of resource-rich coastal waters (especially the U.S. east coast and Gulf of Mexico) is required. There have been a large number of ship groundings owing to depths that were shallower than charted. It would be desirable to have more precise bathymetric maps (accuracy to ±0.3 m) prior to further leasing.

We recommend an early evaluation of various shallow-water survey techniques for coverage, maximum depth, and cost. This evaluation should include the Bathymetric Swath Survey System, photobathymetry, sidescan sonar systems, Airborn Laser Hydrography, and Satellite Hydrography. These evaluations are an industry requirement for technology transfer; to be realistic they should be undertaken both as in-house studies by federal agencies and as independent, outside (university or industry) studies.

The current trend to digitize the bathymetric data should be continued, and NOAA, in conjunction with other concerned agencies and the growing community of industrial and academic users, should review the usefulness of the data's format.

Positioning and Navigation

All positioning requirements are for underwater points, mostly on the ocean bottom.

Offshore Positioning

Due to the continued increase in offshore exploration activities, we recommend the concept of an offshore cadastral survey. To acquire the desired offshore cadastral survey accuracy of ±5 m, techniques and instruments must be developed that will also be required to determine positions of large oil wells to within ±5 m and to recover them in case of blow-outs.

Deep Ocean

Techniques and instruments must be developed to achieve the desired accuracies ranging from ±1 m to ±10 m in deep-ocean work in the following fields:

Mining: ±10 m
Territorial boundary (22 km): ±5 m
Ocean-bottom control net: ±1 m

Permanent stations should be established on at least *10% of the ocean floor of interest* for national needs in engineering, research, and operations, with an accuracy of ±1 m. There should also be a study of various types of benchmarks to be used for defining permanent stations.

Surface and Under-Ice Navigation

The complete availability of today's transit satellite navigation system and tomorrow's GPS satellite system is crucial to the majority of marine geodesy programs and requirements. We recognize that these systems are designed and funded by the U.S. Department of Defense (DOD) to meet national defense needs, and such applications are their primary reason for existence. At present there is no institutional recognition of the secondary fact that these systems are a national asset and are vital in current and future research and exploitation of the oceans.

We strongly recommend the consideration of civil marine geodesy needs in secondary uses of navigation satellites. Since formal DOD/Department of Transportation (DOT) coordination is now established for radio navigation (as described in the Federal Radio Navigation Plan), it would seem logical to make the DOT Navigation Council or one of its subunits the point of contact for national civil use of these satellites.

We also urge the creation of a program to determine the feasibility of under-ice navigation of merchant bulk-carrier submarines.

Plate Tectonic and Seafloor Spreading

Experimental studies could contribute to the explanation of some of the problems related to geodynamics, such as the correlation of plate movements with earthquake predictions; however, no systems are in use to make these measurements in the ocean. Since the relative movements of the plates range from 2 to 20 cm/yr, precision transponders could measure the movement rate to the desired accuracy of 1 cm/yr at the spreading center. Since appropriate designs for these precision transponders exist, they should be built and tested at deep sea, and appropriate software for the data must be developed.

Ocean Surface Topography, Mean Sea Level, Tidal Variations

The panel strongly recommends the resolutions of the International Symposium on Interaction of Marine Geodesy and Ocean Dynamics held in Miami in January 1979:

> *Recognizing the value of global and regional satellite techniques for the solution* of oceanographic and geodetic problems, we recommend that a state-of-the-art satellite altimeter with at least ±10 cm accuracy and with at least ±10 cm orbital tracking, be launched immediately.

Article (cont. on p. 410)

Forum

Methane in Association With Seismic Activity

It has been hypothesized that upward movement of vast quantities of methane gas from the earth's mantle is a causative agent of earthquakes [*Gold*, 1979]. Much of this hypothesis rests on accounts of flames and/or loud, booming noises ("brontides") accompanying seismic events, possibly caused by the explosive release of this "primordial" methane to the atmosphere [*Claflin-Chalton and MacDonald*, 1978; *Gold and Soter*, 1979]. This speculation has generated much controversy because it implies a nonbiological origin for petroleum, as well as the presence of an abundant, potentially harvestable supply of energy in the mantle [e.g., *Nature, 1982; Eos*, 1983]. However, there is a paucity of experimental data to either support or contradict this hypothesis. Because of this continuing, unresolved controversy, I have decided to publish some observations made several years ago with respect to methane emanations during an earthquake that struck near Mammoth Lakes, Calif. [*Oremland*, 1979]. It is of significance that this region lies in close proximity to Owens Valley where accounts exist of flames emanating from the ground during the 1872 earthquake [*Claflin-Chalton and MacDonald*, 1978; *Gold*, 1979].

One possible test of Gold's hypothesis would be the demonstration that dramatic releases of methane frequently accompany seismic activity. Although it does not necessarily follow that methane released during seismic events is of primordial origin (e.g., biogenic or thermogenic methane entrapped near the surface could be released by strong earth movements), the consistent presence or absence of unusually large plumes of methane in association with earthquakes would either lend support to or contradict the hypothesis, respectively. An earthquake of 5.7 magnitude (Richter) struck about 30 km southeast of Mammoth Lakes, California, at 9:45 A.M. on October 4, 1978 (for details see *Savage and Clark*, [1982]). The depth of the epicenter was 15.6 km [R. Cockerhan, personal communication, 1983]. The initial shock lasted several seconds, and a series of aftershocks of diminished intensity occurred for several hours thereafter. Eyewitnesses at Hot Creek, a geothermal stream having several fumaroles, reported the sudden release of large quantities of steam and gases at the time of the first shock. These emanations were of sufficient magnitude to panic the few bathers present, and park officials immediately closed the area. There were no observations of flames exiting the ground. Because I had established a record of the methane content of some of the Hot Creek gas seeps 57 days prior to the earthquake, and because the creek was studied previously with respect to its chemistry and gaseous emanations [*Mariner and Wiley*, 1974], it was possible to determine if any dramatic increase in the methane content of these geothermal gases occurred soon after the initial shock of this seismic event.

Table 1 lists the methane concentrations of two proximate gas seeps (A and B) and two large fumaroles (C and D). Seep A consisted of a slow trickle of bubbles (about 25 cc/min) emanating from warm sediments (50°C) located near the stream bank (water depth about 10 cm). Seep B was located about 1 m away in slightly deeper water (depth about 25 cm), had a faster gas flow rate (about 100 cc/min), and emanated from a more rocky bottom than seep A (sediment temperature = 50°C at seep B). Methane concentrations in the gases from both seeps were low and actually decreased somewhat with the arrival of the earthquake. These methane values are in agreement with the data of *Mariner and Wiley* [1974]. Fumaroles C and D were located about 50 and 75 m, respectively, away from seep A and on the opposite stream bank. Prior to the quake, they were senescent and demonstrated minimal gas ebullition (they were not sampled). However, after the first shock and for several subsequent days they violently

TABLE 1. Methane Concentration in Gases From Hot Creek Seeps (A and B) and Fumaroles (C and D)

Site	Percent Methane in Gas Phase		
	Sept. 17, 1978	Oct. 4, 1978	Oct. 9, 1978
A	0.16	0.12	0.12
B	0.07	0.06	ND
C	ND	0.01	0.01
D	ND	0.01	0.01

Gases were collected by displacement of water in a capped funnel. The collected gases (50 cc) were next drawn up into a syringe, and the contents were injected into sealed, vented serum vials (volume = 5 cc). Analyses were performed within 3 hours of sample collection. Collection of gases on Oct. 4, 1978, were made within 3 hours after the first shock. Samples were analyzed on a Varian series 1400 flame ionization gas chromatograph equipped with a Porapak Q column (305 × 0.64 cm; N_2 carrier flow = 30 cc/min). Limit of detection was about 0.0005%. ND = not determined.

extruded gas bubbles and silt. Fumarole C even spawned a 3 m high water geyser as a consequence of the earthquake. Therefore, new materials were being brought to the surface; however, the methane content of gases emanating from these hot fumaroles (water temperature = 82°C) was about an order of magnitude lower than that of the bubbles exiting the cooler seeps (Table 1). None of the gases collected was combustible.

The higher methane concentrations of the gases at seeps A and B were due to the presence of methanogenic bacteria in the warm and reducing sediments (they had an H_2S odor) surrounding the seeps. Thermophilic methanogenic activity is a common occurrence in hot springs [e.g., *Ward*, 1978], and anaerobic incubation of sediments taken near the seeps demonstrated abundant biological methane production at 62°C (Figure 1). Methanogenesis was blocked by addition of chloroform (Figure 1), an inhibitor of methanogenic bacteria [*Bauchop*, 1967], and, in addition, methane production rates were stimulated seventeenfold by addition by hydrogen to the sediments (data not shown). The high temperatures at fumaroles C and D exceed the physiological range of most thermophilic methanogens [*Zeikus and Wolfe*, 1972; *Ward*, 1978], and therefore the lower methane content of the fumarole gases was probably a consequence of these organisms being absent from those environments. Further evidence for the active presence of methanogenic bacteria near the seeps but not the fumaroles can be inferred from the presence of traces of hydrogen in the fumarole gases (0.03–0.07%) but not in the seep gases. Hydrogen is commonly associated with geothermal gases [*Lyon*, 1974], and because it is a common substrate of methanogenic bacteria, it would be removed from gases that transit sediments harboring an active flora of these organisms.

It is therefore evident that increases in the methane content of geothermal gases did not accompany this earthquake and that methane remained a minor component of the gases. Furthermore, increases of methane were not observed during a 1974 eruption of the Kilauea volcano in Hawaii, and concentrations in collected gases remained below 1.4 ppm (R. Lamontagne, personal communication, 1983). It has been argued that one might not observe liberation of methane in volcanic regions if mineral-catalyzed oxidation of methane to carbon dioxide occurred [*Gold*, 1979]. However, experimental evidence does not support this contention [*Sackett and Chung*, 1979]. Furthermore, the oxidation reaction envisaged would have to operate at near 100% efficiency to account for the low methane values observed in Hot Creek and Kilauea, a feat that is difficult to achieve for a vast volume of methane quickly transiting a hot mineral region during an earthquake. Finally, as noted at the outset, Hot Creek lies in proximity to the region where accounts of flames escaping the earth were recorded during the Owens Valley earthquake of 1872 and were cited as supportive evidence for the methane "deep gas" hypothesis [*Gold*, 1979].

It should be noted, however, that methane can be an abundant component (i.e., >40%) of the gases of mud volcanos [*Reitsema*, 1979]. In addition, significant levels of methane (about 2.5%) were observed in some of the gases collected during a 1977 Kilauea eruption [*Craeber et al.*, 1979]. In both cases, however, the investigators were able to attribute the source of the methane to pyrolysis of buried organic matter. I have observed a high methane content (about 11%) in gases exiting the mud-flow debris region on Mount St. Helens. However, the presence of both ethane and propane in the gas as well as the fact that the site was located on top of 600 feet of hot, recently buried organic-rich debris lends further credence to a shallow pyrolytic origin (with perhaps a biogenic contribution as well) for the methane rather than a deep "primordial" one [R. S. Oremland, unpublished data, 1983].

The observations presented in this report contradict the methane "deep gas" hypothesis of *Gold* [1979]. It must be stressed that any gases released during seismic events or along rift zones may become relatively enriched in methane because of contributions made by liberated pockets of ancient or recent methane entrapped within the crust. This gas may have been formed by biogenic (as in the case of Hot Creek) or thermogenic mechanisms occurring within the crust. Thus, observations of isotopically heavy methane ($\delta^{13}CH_4 = -20$ to -15 per mil) in association with plumes of ^3He emanating geothermal regions [*Welhan and Craig*, 1979; *Gutsalo*, 1980; *Lupton and Craig*, 1981; *Welhan et al.*, 1981] does not prove a mantle origin for the methane because the gas may have been "stripped" out of the crust with upward movement of ^3He. Furthermore, identification of sources of methane that are based primarily on carbon isotopic composition of the gas can be clouded by the activities of methylotrophic bacteria which can enhance the ^{13}C component of the methane [*Silverman and Oyama*, 1968; *Barker and Fritz*, 1981; *Coleman et al.*, 1981] and give it a thermogenic character. Such data, when used to identify sources of "primordial" methane, should be interpreted with caution.

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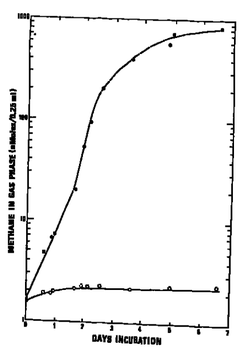

Fig. 1. Methanogenesis in Hot Creek sediments incubated statically in the dark at 62°C. Sediments were collected with a plastic core liner (upper 5 cm of sediment) from a warm (54°C) fumarole located near seeps A and B; 50 cc of sediment were placed into 250 cc Erlenmeyer flasks that contained 75 ml of fumarole water. Flasks were gassed with N_2 for 5 min and then sealed with black rubber stoppers. Open circles, flask containing 0.1 ml of chloroform; closed circles, uninhibited flask. Final methane levels achieved in the uninhibited flask (412 μmoles) corresponds to about 8% of the gas phase volume. Addition of 50 cc of H_2 to another uninhibited flask caused an immediate, seventeenfold stimulation of methane production rates (data not shown).

Article *(cont. from p. 409)*

Also recognizing that improved satellite techniques can resolve many small-scale oceanographic problems, we recommend the development of space instrumentation with at least an order of magnitude improvement in accuracy and the incorporation in the space systems of ancillary instruments to measure such phenomena as sea state, sea surface temperature, ice, salinity, and color, and further recommend that these space programs be undertaken on regional and global scales on a continuous basis.

Finally, recognizing the need for additional surface and subsurface measurements in solving oceanographic and geodetic problems, we recommend that an ocean monitoring system and data handling facility be developed and implemented concurrently with the satellite system.

Tsunamis

To improve the reliability of tsunami prediction, we recommend development of a deep-water system to measure tsunami wave height in real time. This system would provide a supplemental parameter to the tsunami warning system and would be of immense use if a failure of the tide gauge systems occurs, as it did in the December 1979 tsunami.

Conclusion

After the technical recommendations, the panel urged that a study be made to investigate the economic benefit-to-cost ratio for each specific recommendation, and concluded with the following proposal:

Since marine geodetic programs are distributed within several federal agencies, which due to duplication of programs waste user's time to locate a right agency for obtaining information, we strongly recommend that a dynamic group be formed to conduct marine geodetic program direction; this group should be within one federal agency and responsive to all ocean applications programs. This group should be advised by all segments of the involved scientific and user community in the tradition of the Office of Naval Research and the National Aeronautical and Space Administration.

Acknowledgments

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News

Volcanic Sulfur Dynamics

Gaseous sulfur in the aerosol clouds produced by the eruptions of Mount St. Helens and El Chichón is the current focus of research on the effects of matter injected into the atmosphere by volcanoes. Recent research shows that new particles of sulfuric acid are formed up to 3 months after an eruption and that these particles can continue to grow for more than half a year following an eruption. These sulfuric acid particles may alter the earth's climate by interfering with the transmission of radiation from the sun into the lower atmosphere and of infrared radiation from earth back out to space. Furthermore, evidence published last month claims that sulfur emissions during noneruptive phases may be the main source of volcanic sulfur in the atmosphere.

Although effects of sulfuric acid are minimal in the troposphere (which extends to approximately 15 km above the earth at the equator and to 9 km at the two poles), it causes measurable changes in the flow of radiation in the stratosphere (the next major layer above the earth, ranging in thickness from 15 km at the equator to 50 km at the poles). Ongoing research aims to assess the complete impact of sulfur and its derivatives on the chemistry of the atmosphere. According to M. Patrick McCormick of the National Aeronautics and Space Administration (NASA), the May 1980 eruption of Mount St. Helens and the April 1982 eruption of El Chichón provided researchers with an experiment in nature at a time when there is sound technology with which to conduct investigations. The scale of this experiment is suggested by the volume of sulfur involved: The stratosphere was injected with approximately 7.5×10^7 kg of sulfur by the 1980 Mount St. Helens eruption (*Eos*, August 10, 1982, p. 601), and the 1982 El Chichón eruption infused an even greater amount, recent work shows.

Sulfuric acid (H_2SO_4) is the product that directly interferes with solar radiation. The amount of atmospheric H_2SO_4 formed from an injection of sulfur is a function of the sulfur's residence time in the atmosphere and the oxidation and hydration rates it undergoes there.

Although the exact conversion rate of sulfur to sulfuric acid is still under investigation, it is more rapid in the stratosphere than in the troposphere because of higher photochemical activity caused by stronger solar radiation at that level of the atmosphere. The oxidation process leading from sulfur to sulfur trioxide (S, SO, SO_2, SO_3) and the subsequent hydration to H_2SO_4 varies with the availability of water vapor, which fluctuates in different regions over the earth. (Most volcanic sulfur is injected into the atmosphere as sulfur dioxide.)

In 1981, A. S. Kabanov and S. S. Khmelevtsov, of the Experimental Meteorology Institute in the USSR, speculated on the mechanism of sulfate aerosol formation in the stratosphere. They proposed that droplets grow when sulfuric acid molecules adhere to existing water droplets, formed as stratospheric water vapor passes into the liquid phase.

By virtue of vertical mixing and water precipitation, the troposphere is cleansed of sulfur products much more quickly than the stratosphere. The residence time of sulfur products is measured in days to weeks in the troposphere, whereas it is 1–3 years in the stratosphere.

D. J. Hofmann and J. M. Rosen, reporting in *Geophysical Research Letters* in April 1983 on the amount and mass of sulfuric acid aerosol produced by El Chichón, concluded that new particles of sulfuric acid were formed for about 3 months after the eruption. When particle formation ceased, though, particle growth was evident 7 months after the eruption. Their observations, made with three balloon-borne optical particle counters, revealed two layers of aerosol particles in the stratosphere. The higher layer, located at 25 km, consisted of 80% sulfuric acid, while the lower layer, hovering around 18 km, consisted of 60–65% sulfuric acid, estimate the University of Wyoming scientists. Data also indicated possible partial depletion of water at 25 km because of the conversion of gaseous sulfur to sulfuric acid.

Foremost among the instruments used to measure aerosol dispersion is the light detection and ranging (LIDAR) remote sensing system. The device operates by shining light into space. Backscattering of the lightwaves by particles in the atmosphere produces an echo that is then compared with atmospheric heights, and a measure of the dispersion is then calculated. While unable to distinguish between specific compounds, LIDAR can determine the position and relative size of an aerosol cloud of volcanic origin.

Arlin Krueger, also of NASA, said that systems used to measure sulfur dioxide include the Total Ozone Mapping Spectrometer (TOMS) number 7 and the Solar Backscatter Ultra Violet (SBUV), both on the Nimbus-7 satellite. Although these instruments were designed to measure ozone, they can distinguish sulfur dioxide from ozone by the difference in the wavelengths of the radiative energy the compounds absorb. According to Krueger, the volume of sulfur dioxide measured by the systems employed by NASA is less than is implied by the size of the aerosol cloud; there may be a large, undetected volume of sulfur bound in another form, he said.

Following the 1980 eruption of Mount St. Helens, Alan R. Bandy of Drexel University and his collegues embarked on project RAVE (Research on Atmospheric Volcanic Emissions), an effort by NASA and university scientists to investigate the detailed chemical nature of volcanic plumes. Research conducted by the team using the LIDAR system, among others, is expected to expand the basis for diagnosing the major processes in volcanism.

In a 1982 paper, the team stressed that "better estimates of the magnitude and variability of volcanic emissions are required if the importance of this natural source of atmospheric constituents and the resulting effect on atmospheric chemistry and burdens of species are to be elucidated." An important result of a RAVE experiment (conducted by repeatedly traversing the volcanic plume) reported in 1982 was the estimate of sulfur dioxide flux from Mount St. Helens as 9×10^4 kg/day on September 22, 1980.

The use of direct measurements of volcanically injected sulfur and a proposed classification of volcanic activity, including eruptive and noneruptive phases, are the main advantages of a new model that assesses atmospheric sulfur contributed by volcanoes, according to a paper in the April 20 *Journal of Geophysical Research*. H. Berresheim and W. Jaeschke of the Center for Environmental Protection at the J. W. Goethe-University, Frankfurt/Main, Federal Republic of Germany, argue in their paper that emissions of sulfur during noneruptive phases, previously neglected by researchers, are the main source of the volcanic sulfur in the atmosphere.

In the same issue, the University of Wyoming's Rosen and Hofmann report on the newly discovered quasiannual variation of concentrations of condensation nuclei. Condensation nuclei are liquid or solid atmospheric particles that instigate the condensation of vapors into aerosols. Although the team concludes that there is no single explanation for the variance of condensation nuclei concentration, it speculates that sulfuric acid resulting from recent eruptions may play a role. Rosen and Hofmann say that study of condensation nuclei, thought to be the link between precursor gases and aerosol formation, will aid in developing predictive models and understanding stratospheric aerosol chemistry.—*MEG*

EOS

Transactions, American Geophysical Union

The Weekly Newspaper of Geophysics

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Cover. Large gas and ash eruption of Sakurajima Volcano near Kagoshima in Kyushu, Japan, on September 13, 1981. A series of powerful eruptions that day produced extensive ashfall and measured flux of SO_2 of greater than 11,000 tons per day. Sakurajima has been almost continuously active since 1956; extensive measures have been taken to monitor its activity and preparations made for rapid evacuation of local residents. (Photograph courtesy of Stanley N. Williams, Department of Earth Sciences, Dartmouth College, Hanover, N.H.)

Would you like to be on the cover of *Eos*? Do you have photographs (preferably black and white) of geophysical phenomena? Or of unusual experimental results or graphs and charts with both aesthetic charm and scientific interest? *Eos* would like to consider them for publication on the cover. Send your favorite photo with a short (50-200 words) explanation that can serve as a caption, or you may submit a more extensive news item or even a short article to accompany a proposed cover. Captions will be by-lined. If the material has been previously published, please supply a copyright release from the original publisher. Send to *Eos* Cover, AGU Publications Office, 2000 Florida Avenue, N.W., Washington, DC 20009.

Pioneer 10 Leaves Solar System

The National Aeronautical and Space Administration's (NASA) unmanned spacecraft, Pioneer 10, was expected to leave the outer reaches of our solar system on June 13, 1983. (The division between the solar system and outer space is defined as the edge of the sheath of influence of the solar wind; this sheath is called the heliosphere.) On its way to space beyond our solar system, Pioneer 10 will pass close enough to Neptune and Uranus to obtain data which may be useful in determining whether or not "Planet X" exists. Planet X is the hypothetical cause of Neptune's and Uranus' perturbed motion, so far unexplained by earth observation. In addition, as it leaves the heliosphere, scientists hope Pioneer 10 will map the apex of the solar wind teardrop.

Pioneer 10, launched on March 2, 1972, was intended to last for about 2 years. When Pioneer 10 leaves our solar system in June and heads into interstellar space, NASA will celebrate its success. Ceremonies will be held in the Capitol, the Ames Research Center where the Pioneer 10 project is being manned, and at TRW in southern California where the spacecraft was built.

Now the spacecraft is nearly 2.8 billion miles from the sun. Tracking data are being obtained regularly and will continue to be received, even when it is twice as far from earth as it is now.—*PMB*

Combating Illiteracy

A science course for nonscientists at Columbia University's Columbia College that was created in 1981 as an experiment to combat "the national crisis of scientific illiteracy" has received major new foundation support and has achieved a permanent place in the college's curriculum.

The course, 'The Theory and Practice of Science, has received a $240,000 grant from the Andrew W. Mellon Foundation, according to Robert E. Pollack, college dean, professor of biological sciences, and originator of the course. The grant will be used for the preparation and publication in 1985 of a textbook, titled *The Scientific Experience*, which will permit the course to be taught at other schools around the country.

The course is designed to expose students to the way in which scientists think and reach conclusions about the physical world, rather than to teach them the substance of only one discipline. The course "is unique," Pollack said. "It is not a history or philosophy of science, but a study of pure science, to show what scientists think is elegant about their subject." Pollack teaches the course with Herbert Goldstein, professor of applied physics and nuclear engineering, and Jonathan Gross, professor of mathematical statistics and computer science. Funds from the Mellon grant will enable the addition of four other faculty members and the addition of a second section of the course in the 1983–1984 academic year. More sections are planned for future years, Pollack noted. The four faculty joining the original core are Samuel Eilenberg, University Professor Emeritus; Darcy Kelley, associate professor of biology; David Helfand, associate professor of physics; and Robert Crease, philosophy instructor.

The course, which began with 15 students and funding from the Exxon Education Foundation and an anonymous alumnus, doubled in size in the 1982–1983 academic year with a grant from the Atlantic Richfield Foundation.

NEXRAD Negotiations

Two firms have been selected for negotiation for preproduction models of NEXRAD, the next generation weather radar system that aims to improve severe weather forecasting. The 40-month, cost-plus-fixed-fee con-

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News (cont. from p. 411)

tracts, each valued at $20 million, were awarded to Raytheon Co. of Wyland, Mass., and to Sperry Corp. of Great Neck, N.Y., according to the National Oceanic and Atmospheric Administration (NOAA).

The contract awards represent the second of four phases in the 10-year process of the development and deployment of a national weather radar system to replace existing but aging units. One of the companies will be selected in late 1986 for a contract for limited production of the radar units. Full production and installation of the first operational units are expected by early 1988.

NEXRAD is a joint effort of the Commerce, Defense, and Transportation departments to develop an advanced radar with Doppler capabilities that meet the needs of NOAA's National Weather Service, the Federal Aviation Administration, and the U.S. military.

Geophysicists

The following AGU members were recently elected to membership in the National Academy of Sciences: ***Thomas M. Donahue***, chairman of the department of atmospheric and oceanic science at the University of Michigan; ***Wilford R. Gardner***, chairman of soils, water, and engineering at the University of Arizona; ***Stanley R. Hart***, professor of geochemistry at the Massachusetts Institute of Technology; ***Jerome Namias***, resident meteorologist at the Scripps Institution of Oceanography; and ***Norman F. Ness***, chief of the laboratory for extraterrestrial physics at NASA's Goddard Space Flight Center. In addition, ***Ikuo Kushiro***, a staff member at the Carnegie Institution of Washington's Geophysical Laboratory and professor of petrology at the University of Tokyo, was elected a foreign associate of the Academy. ***William A. Nierenberg***, director of the Scripps Institution of Oceanography, was elected to the National Academy of Engineering. He was cited for outstanding engineering and scientific contributions in the field of oceanography, with particular application to deep ocean operations.

Wallace Broecker, at the Lamont-Doherty Geological Observatory, ***Warren Hamilton***, at the U.S. Geological Survey, and ***Patrick Hurley***, at the Massachusetts Institute of Technology, were elected honorary members of the Geological Society of London.

Cesare Emiliani, chairman of the University of Miami's geology department and director of the undergraduate marine science program, has been awarded the Vega Medal by the Swedish Geographic Society in recognition of his isotopic analysis of deep-sea sediments that he used to study the ice ages. Previous recipients include oceanographer ***H. U. Sverdrup*** (1930) and geophysicist ***Maurice Ewing*** (1965).

Hollis D. Hedberg, Princeton University emeritus professor of geology, received the American Geological Institute's Medal in Honor of ***Ian Campbell***. The medal is awarded annually to scientists whose careers are comparable to Campbell, who taught geology at the California Institute of Technology from 1931–1959, and then became California's state geologist. Campbell, AGI president in 1961, died in 1978.

Ian MacGregor has been appointed deputy director of the National Science Foundation's Division of Earth Sciences. He had been chief scientist in the Office of Scientific Ocean Drilling.

Albert Rango has been appointed chief of the Hydrology Laboratory at the Department of Agriculture's Agricultural Research Service in Beltsville, Md. The major research objectives of the laboratory are applying remote sensing to hydrology and water resources, investigating climate variability and its impact on soil moisture, and applying hydrological modeling to large areas and to pollution from nonpoint sources. A 10-year veteran of NASA's Goddard Space Flight Center, Rango was most recently head of Goddard's Hydrological Sciences Branch.

Henry Spall has been appointed associate chief of the Office of Scientific Publications at the U.S. Geological Survey National Center in Reston, Va.

In Memoriam

Jacob Otnes, national correspondent for Norway to the International Association of Hydrological Sciences (IAHS) and director of the Norwegian Hydrological Service, died January 17, 1983. A member of the Hydrology section, he joined AGU in 1961.

Leon Tison, Secretary General of the IAHS from 1948 to 1970 and the recipient of the first International Hydrology Prize in 1981, died on December 25, 1982.

Albert Rango

Books

AGU New Books

The Scientist and Engineer in Court
M. D. Bradley, 116 pp., softbound, 1983.
AGU members: $9.80; others: $14.

With increasing frequency, scientists and engineers are called on to serve as expert witnesses in court, yet few know their duties and fewer still know the procedures in a lawsuit. Many experts find the courtroom confusing, with proceedings that seem arcane and decisions that seem strange or even illogical. Outsiders are easily lost in the ceremony and drama of a lawsuit, especially if their expertise prepares them to deal more with facts than with values, with collaboration instead of advocacy, and with answers rather than settlements. Expert witnesses need preparation to understand what happens in lawsuits and to whom and why it happens.

Today courts are settling disputes with significant technical and scientific components and need expert witnesses to analyze scientific information. An expert's testimony helps a court accept scientific and technical information, process it for its substantive worth, and form it into a legal decision. But the expert needs more than technical skills. In order to function effectively as an expert witness, he also needs to understand the hidden dimensions of courtroom interactions, the tactics developed by lawyers in an adversarial proceeding, and the use of technical facts in legal decision making. Scientists and engineers can no longer afford the luxury of ignorance about the judicial process.

This volume clarifies the elements of a lawsuit, defines common legal terms, and offers a guide to the courtroom drama. Assuming that experts wish to be knowledgeable about the trial, it explains which evidence is admissible, the tactics of cross examination, and the need for effective communication with the judge or jury. It deals with the practical aspects of courtroom appearance and the calculation of witness fees. And it encourages experts to understand their role as learners in an evolving legal system. The message is simple: "Scientists have knowledge that courts find useful when deciding lawsuits; therefore, scientists should testify when asked as expert witnesses in court." By adding knowledge of the courtroom proceedings to an established technical or scientific expertise, the expert becomes a more valuable and effective witness.

Contents

Classified

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For further information, call toll free 800-424-2488 or, in the Washington, D. C., area, 462-6903.

POSITIONS AVAILABLE

Marine Research Associate II. Analyze and interpret time series of vertical acoustic travel time and bottom pressure. Prepare progress reports and scientific manuscripts on these results. Assist in planning experiments and participate in scientific cruises. Ph.D. in physical oceanography plus experience in computer programming with times series applications in FORTRAN. Submit application and resume by August 15, 1983, to: Dr. D.R. Watts, Marine Research Associate II Position, University of Rhode Island, P.O. Box 357, Kingston, Rhode Island 02881.

An affirmative action/equal opportunity employer m/f.

Research Positions for Mathematical Physicists. Applications are invited for several research positions at the Center for Studies of Nonlinear Dynamics, La Jolla Institute, beginning summer 1983. Current research involves work on nonlinear wave-wave interactions, acoustic, optical, and radio wave propagation in random media, and fluctuation phenomena in the statistical mechanics of chemical and geophysical systems. Physicists and applied mathematicians who are interested in working on problems of the above type should send resumes and arrange for three letters of recommendation to be sent to Dr. Stanley Flatte, Director, CSND, La Jolla Institute, 8950 Villa La Jolla Drive, Suite 2150, La Jolla, California 92037.
La Jolla Institute is an equal opportunity/affirmative action employer.

Assistant Professor/Crustal Reflection Seismology: University of Wyoming. A non-tenured position to conduct and direct research in reflection seismology is likely to become available on 1 August 1983 for a period of two yuears. Project involves processing and interpretation of COCORP and other deep crustal reflection data with Robert Burridge and Scott Smithson as the principal investigators.

Ph.D. or expected completion within six months required. Applicant must be experienced in processing and interpreting crustal reflection data. Responsibilities include supervising graduate students and conducting own research in processing and/or interpretation. Opportunity to become involved in an integrated approach to reflection seismology working with colleagues in electrical engineering and mathematics and to become involved in seismic data acquisition. Deadline for applications is July 1, 1983. Interested applicants send a resume and names of three references to:

Scott Smithson
Department of Geology and Geophysics
University of Wyoming
P.O. Box 3006, University Station
Laramie, WY 82071.

The University of Wyoming is an equal opportunity/affirmative action employer.

Geohydrologist. Lawrence Livermore National Laboratory currently has an opening for a Geohydrologist with an MS or Ph.D. degree or equivalent experience. You will support various programs including nuclear waste isolation and hydraulic fracturing of underground media. Assignment is a combination of field work and numerical modeling of porous or fracture flow of ground water utilizing existing computer codes or developing new codes to model ground water flow. Position requires a background in both numerical modelling and field geohydrology and applicants should have experience in application of numerical modeling to practical groundwater problems, including experience in dealing with contaminated groundwater.

LLNL is an applied science R&D facility operated by the University of California for the U.S. Department of Energy. We are located in Livermore, California, 40 miles east of San Francisco.

Send resume in strict confidence to Art Wong, Professional Employment Division, LAWRENCE LIVERMORE NATIONAL LABORATORY, P.O. Box 5510, KES-063, Livermore, CA 94550. U.S. Citizenship is required.

An equal opportunity employer M/F/H/V.

Research Associate/Petrography-Petrology. To join a research effort aimed at understanding the condensation history of the solar system by mineralogical, chemical, and isotopic studies of tiny inclusions in primitive meteorites. Applicant need not have previous experience with meteorites but should be a superb petrographer, skilled in the use of the SEM and electron probe. Successful candidate will be dedicated, productive, an effective communicator both orally and in writing, and will have Ph.D. in hand. Vacancy expected in late summer or early autumn 1983.

Send resume and names of three references to: L. Grossman, Department of the Geophysical Sciences, University of Chicago, 5734 S. Ellis Avenue, Chicago, IL 60637.

The University of Chicago is an equal opportunity/affirmative action employer.

Research Professor in Marine Geoscience/University of Rhode Island (Marine Geoscientist). The Graduate School of Oceanography invites applications for a research professorship in Marine Geoscience whose salary and rank are negotiable. Preference will be given to candidates who have clearly demonstrated abilities and interest in, but not necessarily limited to paleomagnetism. The position is funded by contracts and grants, however the research professor holds full faculty rights in addition to other benefits. The paleomagnetic facility at GSO is fully equipped, fully operational and oriented towards rapid measurement of large numbers of soft sedimentary samples. Applications are now open for the position which will become available about January 1, 1984.

Send letters of application, resume, and names and addresses of three professional references to: Roger L. Larson, Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island 02882.

An affirmative action/equal opportunity employer m/f.

Research Scientist/Space Plasma Physics, University of Iowa. A research position is available in the Department of Physics and Astronomy, The University of Iowa, for theoretical and interpretative studies of waves in space plasmas. Specific emphasis is on theoretical investigations of wave-particle interactions in planetary magnetospheres and in the solar wind. These investigations are to support the interpretation of data being obtained from spacecraft projects such as Dynamics Explorer, International Sun Earth Explorer and Voyager. The applicant must have a Ph.D. with good qualifications in plasma physics theory and shoud have some experience in the interpretation of space plasma physics data.

Send a resume and the names of three references familiar with the applicant's work to: D.A. Gurnett, Department of Physics and Astronomy, The University of Iowa, Iowa City, Iowa 52242, telephone 319-353-3527.

The University of Iowa is an affirmative action/equal opportunity employer.

Opportunities for Graduate Studies in the Atmospheric Sciences at the Georgia Institute of Technology. Openings are available for outstanding individuals seeking an M.S. or Ph.D. degree in graduate studies in the atmospheric sciences. For successful applicants, these positions include 1/2-time research assistantships with starting salaries ranging from $7,000 to $12,000/12 months, depending on the degree being sought and the student's qualifications. All tuition and fees are also covered by the institute.

The Atmospheric Sciences Program at Georgia Tech is part of the School of Geophysical Sciences and is uniquely structured academically in that major emphasis is given to three areas of atmospheric sciences, namely, Dynamic Meteorology, Physical Meteorology, and Atmospheric Chemistry. Major research efforts in which students are currently involved include studies in wind and solar power, climate modification, air pollution, uses of satellite meteorology, measurements of aerosols in the atmosphere, modeling of planetary circulations, mesoscale and boundary layer dynamics, development of laser instrumentation for the detection of atmospheric aerosols and gases, global airborne measurements of atmospheric trace gases, photochemical and gas kinetic studies of atmospheric transformations, studies of biogeochemical cycles, and one-, two- and three-dimensional chemical and dynamic modeling of the troposhere and stratosphere.

Students interested in being involved in these or other exciting Atmospheric Sciences projects at Georgia Tech should write for information to:

Dr. Douglas D. Davis
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, GA 30332.

Atmospheric Modeler/Programmer. Atmospheric and Environmental Research, Inc. has a staff position opening on a project to enhance the assimilation and forecast capabilities of an NWP spectral model by maximizing the model's use of satellite data. The position is for a recent PhD or experienced MS in meteorology or related field with an active interest in global numerical weather prediction. We are especially interested in individuals with expertise in one or more of the following areas: normal mode initialization, optimal interpolation, cloud parameterization and forecasting, boundary layer processes. Computer proficiency is a must—experience with Harris and/or CRAY hardware is desirable. Stimulating, academic-style research environment. Please send resume and names of references to: Dr. Lewis Kaplan, Principal Scientist, Atmospheric and Environmental Research, Inc., 840 Memorial Drive, Cambridge, MA 02139. Telephone 617-547-6207.

Argonne National Laboratory/Chemistry Division. An immediate postdoctoral position is available for atmospheric chemistry studies based on mass spectrometric analysis of the stable isotopic composition of atmospheric trace gases. Problems include source budgets and temporal variations of atmospheric trace gases and determination of atmospheric OH free radical concentrations using stable isotope tracers. Experimental techniques involve preparation of gas samples derived from trace gases using carrier gas train systems with cryogenic and chemical separation methods and precision mass spectrometric analysis. Send resume to: Mr. Walter McFall, Personnel Division, Box D-CHM-80, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439.

An equal opportunity employer.

Engineering Geosciences/U.S. Nuclear Regulatory Commission(NRC). The High-Level Waste Liscensing Management Branch, Division of Waste Management, NRC, invites applications for excellent candidates to fill a variety of anticipated positions in the engineering geosciences.

The positions are related to the regulatory analysis of proposed deep geologic high-level radioactive waste repositories. Disciplines considered are: Hydrology, Geotechnology, Geochemistry, Hydrogeology, Materials Science, Geostatistics, and Statistical Risk Analysis. All applicants must have a strong computer modeling background and the equivalent of a Bachelor's or Master's degree in Engineering or Science. U.S. citizenship is required. Salaries range from GG-7 to GG-12 level, depending on qualifications.

Applications for these potential openings should be received by July 8, 1983. Please send resume or, preferably, SF-171 (Personnel Qualifications Statement) to:

Matthew J. Gordon
U.S. Nuclear Regulatory Commission
Mail Stop 623-SS
Washington, D.C. 20555.

The U.S. Nuclear Regulatory Commission is an equal opportunity employer.

Faculty Position for HREM Specialist/Arizona State University. A tenure-track faculty position at the Associate or Assistant Professor level is available at Arizona State University for a high-resolution electron microscopy specialist to work with the ASU Facility for High Resolution Electron Microscopy within the Center for Solid State Science.

The appointee will hold academic rank and will teach within the university department appropriate to his/her expertise. Qualifications include a doctoral degree in an appropriate area of science, a record of achievement and publication in high resolution electron microscopy and knowledge of related techniques such as microanalysis and microdiffraction. It is expected that the appointee will institute an active research program in electron microscopy or its applications in some area of solid state science using the instrumentation of the Facility and will serve as adviser to Facility users.

Send resume and arrange for three letters of recommendation to be sent to: J.M. Cowley, Center for Solid State Science, Arizona State University, Tempe, AZ 85287, before August 20, 1983.

Arizona State University is an equal opportunity/affirmative action employer.

Chairman—Department of Geological Sciences, Wright State University. The Department of Geological Sciences, invites applications for the position of chairman, to be appointed September 1984. We seek a dynamic individual with administrative talent and an appreciation for research and practice-related educational activities. Rank is at the full professor level and no restrictions have been placed on areas of specialization. The department is active with 12 faculty and an emphasis on professional practice, yet maintaining a firm commitment to basic research.

Send a letter of application, curriculum vitae and names of three references to:

Chairman, Search Committee
Department of Geological Sciences
Wright State University
Dayton, OH 45435.

Wright State University is an affirmative action/equal opportunity employer. Closing date for the position is October 31, 1983.

University of Colorado, Boulder, Geochemist Position. Geochemist with active research program, stable isotopes, radioactive isotopes, and/or trace elements is being sought for a joint appointment in the Department of Geological Sciences and the Cooperative Institute for Research in Environmental Sciences (CIRES) of the University of Colorado.

The one-half time position within the Department of Geological Sciences is tenure track at the assistant or associate professor level with a starting salary of $12,000—$15,000 for the academic year.

Teaching load will be half that of full-time faculty. The position within CIRES will be as a Fellow with appropriate office and laboratory space. One-half academic year salary will be guaranteed by CIRES for two years at the departmental rate, after which incumbent must generate his/her CIRES salary from external sources. Incumbent may augment salary further by generating three months of summer salary from contracts and grants, and consulting.

Applicants with experience, publications, and/or movable existing research equipment preferred. Preferred starting date would be January 1, 1984. Closing date for applications is October 1, 1983.

Applications should include statement of research and teaching interests, experience, a full vitae, and four letters of reference.

Apply to: Professor Charles Stern, Chairman, Geochemist Search Committee, Department of Geological Sciences, Campus Box 250, University of Colorado, Boulder, CO 80309.

The University of Colorado is an equal opportunity/affirmative action, Section 504 employer.

Temporary Faculty Position/UCLA. The Department of Earth and Space Sciences, UCLA, seeks applications for a temporary faculty position in the area of sedimentology, basin analysis, stratigraphy, and regional geology.

A Ph.D. or equivalent is required. There is no restriction as to the level. Duties will include undergraduate and graduate teaching, supervision of theses and dissertations, and development of a research program in the area of specialization. Field-based experience will be taken into consideration. The appointment will begin July 1, 1983, will be full-time nine-month, and will be renewable year-to-year. The department hopes to convert this position in 1984 or later, but has no assurance thereof. Send resume to:

Chairman
Department of Earth and Space Sciences
University of California
405 Hilgard Avenue
Los Angeles, CA 90024.

UCLA is an affirmative action equal opportunity employer.

Hydrogeologist. Converse Consultants is seeking a staff or project level hydrogeologist for investigations involving groundwater quality and supply, waste disposal, mineral and energy development and geotechnical projects. Las Vegas-based, will serve primarily in the southwestern U.S. Opportunity for interaction with an expanding staff of professionals in six regional offices. Excellent salary and advancement potential.

Minimum requirements are an advanced degree in geology plus two to five years experience involving such areas as aquifer testing and modeling, well and well field design, quantitative evaluation of groundwater flow, contractor supervision. Good communication skills are essential. Additional training or experience in geophysics and hydrology is desirable. Contact Dr. Robert F. Kaufmann, Principal Geologist, Converse Consultants, Inc., 4055 S. Spencer Street, Suite 120. Las Vegas, NV 89109.

Howard University/Graduate Faculty Position. The Department of Geology/Geography invites applications for a tenure-track position in geochemistry at rank of assistant or associate professor beginning August 1983. Position involves development of graduate research program at Master's level. Desired specialization includes environmental geochemistry, geochronology, isotope geology. Send letter of application, resume and names of three references to Dr. David Schwartzman, Department of Geology/Geography, Howard University, D.C. 20059.

STUDENT OPPORTUNITIES

Graduate Assistantships/Howard University. Howard University in Washington, D.C., offers a new graduate program for the M.S. degree in geoscience; made possible by a grant from the Gulf Oil Company. Areas of specialization are field geology/geophysics, geochemistry, and meteorology/hydrology with remote sensing. Some stipends and assistantships are available. Potential students should write to Dr. Eric Christofferson, Department of Geology and Geography, Howard University, Washington, D.C. 20059.

AGU

1983 VGP Award Nominations

Nominations are being sought for the 1983 VGP Award, which will be presented at the 1983 AGU Fall Meeting in San Francisco, December 5–10, 1983. The deadline for nominations is July 15.

The award is given for a single outstanding contribution to volcanology, geochemistry, or petrology made during the preceding 5 years. The contribution may be (1) a single outstanding paper published in any journal, (2) a series of papers that, when taken together, constitute an outstanding contribution, or (3) any other contribution that the Selection Committee considers worthy.

Any member of the scientific community is eligible for the award. Although the Selection Committee is encouraged to seek out scientists whose work has not been recognized by the receipt of other awards, this charge is not a restriction on the award. The award may be given to as many as five or as few as zero individuals in any calendar year. Multiple awards may either be shared or separate, as appropriate.

Nominations for the VGP Award may be made by any member of AGU. Each nomination must be accompanied by a written statement of the basis for the nomination. Copies of the contribution(s) for which the person is nominated should accompany the nomination statement if appropriate.

Nominations should be sent to the VGP President (Joseph V. Smith, Department of Geophysical Sciences, University of Chicago, Chicago, IL 60637), or the VGP President-Elect (G. Brent Dalrymple, U.S. Geological Survey, 345 Middlefield Road, MS 19, Menlo Park, CA 94025), or the VGP Secretary (Peter Lipman, U.S. Geological Survey, Denver Federal Center, MS 913, Denver, CO 80225) for forwarding to the Selection Committee

Meetings

Announcements

Flood Risk

A session on Flood Risk will be held at the AGU Fall Meeting in San Francisco, December 5–10, 1983.

During the last 5 years, research has produced many new and improved statistical techniques for estimating flood risk and various quantities of the flood-flow distribution at gauged sites. This session will review these new ideas as well as review *Bulletin 17*, as was revised in September 1981.

Topics should include advantages of regionalization, regional skewness, empirical Bayes estimators, probability weighted moments and the Wakeby distribution, measurement error and its impact, nonparametric procedures, and the use of historical flooding information. A companion session in the afternoon will examine the search for more physically based, extreme-value models in hydrology. The day will close with a special panel discussion chaired by John Schaake, Jr.

Mail one copy of your abstract to Jery R. Stedinger (Hollister Hall, Cornell University, Ithaca, NY 14853), the morning session organizer, by August 15, 1983, and the original and two copies of the abstract to AGU by September 14.

Watershed Models

A session on Treatment of Evapotranspiration, Soil Moisture Evolution, and Aquifer Recharge in Watershed Models will be held at the AGU Fall Meeting in San Francisco, December 5–10, 1983. Following the successful 1981 session, Impact of Richard's Equation, the Water in the Unsaturated Zone and Evapotranspiration Committee has decided to pursue the topic with a session even more specifically devoted to applications.

The session's invited and contributed papers will explore the manner in which the hydrologic phenomena of evapotranspiration, soil moisture evolution (including interglow), aquifer recharge, and aquifer return flows are treated in current (small) watershed and/or river basin models. Papers addressing the physical or conceptual basis for the treatment of the hydrologic components, the detailed structure of the mathematical models, the validity of the approaches taken, the laboratory or field verification of the approaches, the ease of calibration of the subsurface parameters, the experience in use of the models, etc., are welcome.

Prospective contributors should send three copies of an abstract of their paper as soon as possible and no later than July 29, 1983, to H. J. Morel-Seytoux, Department of Civil Engineering, Colorado State University, Fort Collins, CO 80523 (telephone 303-491-5448 or 491-8549). Please mail the original and two copies to Meetings, AGU, 2000 Florida Avenue, N.W., Washington, DC 20009, by September 14, 1983.

Geophysical Year

New Listings

The complete Geophysical Year last appeared in the May 31, 1983, *Eos*.

A boldface meeting title indicates sponsorship or cosponsorship by AGU.

Jan. 16–21, 1984 Penrose Conference on the Evolution of the Central Atlantic Ocean and its Continental Margins, Giens, France. (J. Sougy, Laboratoire de Géologie Dynamique, LA CNRS no. 132, Faculté des Sciences de Saint Jérôme, 13397, Marseille Cedex 13, France; telephone: (91) 98 90 10, ext. 510.)

May 28–June 2, 1984 12th International Congress on Irrigation and Drainage, Fort Collins, Colo. Sponsor, the U.S. Committee on Irrigation, Drainage, and Flood Control. (U.S. Committee on Irrigation, Drainage and Flood Control, P.O. Box 15326, Denver, CO 80215.)

July 19–25, 1984 Symposium on Wave Breaking, Turbulent Mixing, and Radio Probing of the Ocean Surface, Sendai, Japan. (O. M. Phillips, Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD 21218; telephone: 301-338-7034.)

GAP

Aeronomy

0499 Aeronomy (General)
OBSERVATIONS OF THERMOSPHERIC DYNAMICS AT HIGH LATITUDES FROM GROUND AND SPACE
John W. Meriwether, Jr. (Space Physics Research Laboratory, University of Michigan, Ann Arbor, Michigan, 48109)

Comprehensive experimental investigations of the phenomenology of the F-region neutral wind and ion convection at high latitudes combined with improved theoretical modelling efforts have resulted in major advances in our current understanding of thermospheric dynamics of this region. We review the recent progress in this field. (Thermospheric dynamics, review).
Rad. Sci., Paper 3S0785

Exploration Geophysics

0920 Magnetic and electrical methods
THE HARMONIC AND TRANSIENT ELECTROMAGNETIC RESPONSE OF A THIN DIPPING DIKE
P. Weidelt (Bundesanstalt fur Geowissenschaften und Rohstoffe, D-3000 Hannover, West Germany)

An exact solution is given for the electromagnetic induction in a dipping dike of finite conductivity, represented as a thin half-sheet in a nonconducting surrounding. The problem is formulated for arbitrary dipole or circular loop $T_M - R_x$ configurations. The formal solution obtained by the Wiener-Hopf technique is cast into a rapidly convergent triple integral suitable for an effective numerical treatment. A good agreement is found between numerical results and analog measurements available for harmonic excitation. The transient response is obtained as a superposition of the half-sheet free-decay modes and is illustrated by some numerical examples for coincident loops, including a diagram for the approximate determination of conductance and depth of a vertical dike.
GEOPHYSICS, VOL. 48, NO. 7

0920 Magnetic and electrical methods
FINITE-DIFFERENCE CALCULTIONS OF THE TRANSIENT FIELD OF AN AXIALLY SYMMETRIC EARTH FOR VERTICAL MAGNETIC DIPOLE EXCITATION
M.M. Goldman (Department of Geophysics, Colorado School of Mines, Golden, CO 80401) C.H. Stoyer

A finite-difference formulation of the coaxial-loop or wire-loop transient electromagnetic (EM) prospecting systems is used to model the field from a buried cylindrical conductor whose axis is coincident with that of the field system. Solutions are obtained directly in the time domain. The formulation is implicit and two-dimensional (2-D) in space. The variable-directions method reduces each advance of one step in time from one 2-D problem to a large number of one-dimensional (1-D) problems. The result is a reduction in computational effort. In order to avoid including the air in the finite-difference grid, an integral equation approach is used to formulate the surface boundary condition. Thus, two sets of 1-D finite-difference solutions and one Fredholm integral equation solution are required for each step forward in time. Comparison with analytical solutions shows excellent agreement in the case of a four-layer earth.

All computations were carried out for a perfectly conducting basement, but the method can be used for finitely conducting basement as well. If the basement is an insulator, an additional integral equation solution is required on the lower boundary.

Results for a buried cylindrical conductor show that there is a high degree of sensitivity to conductor size. Inversion of transients to a stratified model can be useful if the effect of finite conductor size is taken into account. For cylindrical conductors with lateral extent comparable to or larger than the source-receiver separtion, the inversion results are valid. For conductors with lateral extent small compared with source-receiver separation, the inversion will yield a stratified model which shows better agreement between actual and inverted thicknesses than resistivities. The involved resistivities are somewhat higher than those actually present in this case.
GEOPHYSICS, VOL. 48, NO. 7

0999 General or miscellaneous
GEOTHERMAL PROSPECTING WITH SHALLO-TEMP SURVEYS
L.A. LeSchack (LeSchack Associates, Ltd., P.O. Box 646, Long Key, Florida 33001) J.E. Lewis

The Shallo-Temp® survey is an inexpensive and rapid "first look" geophysical technique that is useful in planning the more traditional and costly reconnaissance drilling geothermal exploration programs. The technique is based on making many soil temperature measurements at 2-m depths over a given exploration area and correcting these measurements for the effects of elevation and surface geologic and meteorologic conditions. Corrections for surface conditions are made with an "annual wave correction model." The output from the model is the normally expected 2-m temperature for the given site at the date for which input data were provided. The difference between the measured and computed 2-m temperature data represents effects of geothermal heat flow. A Shallow-Temp residual map is compared both to a 2-m temperature map for a specific date (September, 1977) and to a mean annual 2-m temperature map for the Coso known geothermal resource area producing the same anomaly pattern in each case. Additional case history studies at Upsal Hogback in Nevada, and Animas Valley in New Mexico provide evidence to suport the applicability of the Shallo-Temp technique throughout the Basin and Range Province. The technique developed is not designed to replace reconnaissance drilling but rather help focus standard reconnaissance programs. The two potentially most reliable applications of the technique are in extending trends where standard reconnaissance holes have been drilled or filling in detail between widely spaced holes, and in surveying for near-surface anomalies that might be developed for direct heating applications.
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GEOPHYSICS, VOL. 48, NO. 7

Hydrology

3130 Groundwater
AQUIFER THERMAL ENERGY STORAGE: AN ATTEMPT TO COUNTER FREE THERMAL CONVECTION
F. J. Molz (Civil Engineering Department, Auburn University, Alabama, 36849), J. G. Melville, O. Güven and A. D. Parr

In previous Aquifer Thermal Energy Storage (ATES) experiments, appreciable free thermal convection was observed. In an attempt to counter the detrimental effects of convection, a dual recovery well system was constructed at the Mobile site, and a third injection-storage-recovery cycle performed. Using a partially penetrating well, cycle 3-3 injection began on April 7, 1982. A total of 56,680 m³ of 79°C water were injected. After 57 days of storage, production began with a dual recovery well system. Due to the dominating effect of nonhomogeneities, the dual well system did not work particularly well, and a recovery factor of 0.42 was achieved. The degree of aquifer heterogeneity at the location of the present experiments was not apparent during previous experiments at a location only 109 m away, although pumping tests indicated similar values of transmissivity. Therefore, aquifers with the same transmissivity can behave quite differently in a thermal sense. Heat conduction to the upper aquitard was a major energy loss mechanism. Water sample analyses indicated that there were no important changes in the chemical constituents during the 3rd set of experiments. There was a 19% increase in total dissolved solids. At the end of injection, the land surface near the injection well had risen 1.39 cm with respect to bench marks located 70 m away. (Aquifer, thermal, energy, storage).
Water Resour. Res., Paper 3W0780

Meteorology

3770 Particles and Aerosols
ON SOME RADIATIVE FEATURES OF THE EL CHICHON VOLCANIC STRATOSPHERIC DUST CLOUD AND A CLOUD OF UNKNOWN ORIGIN OBSERVED AT MAUNA LOA
J. J. DeLuisi, E. G. Dutton, K. L. Coulson, T. E. DeFoor, and B. G. Mendonca (NOAA/ERL/ARL, Boulder, Colorado, 80303)

In this paper we present some results of our initial optical observations of the El Chichon volcanic cloud. These observations were made at the GMCC Mauna Loa, Hawaii Observatory, and consist of lidar profiles, optical thickness, spectral variation in optical thickness and changes in global and direct solar broadband fluxes. Particle size distribution and cloud mass information contained in the optical thickness observations are discussed. It is clear that the atmospheric radiative effects of the El Chichon cloud far exceed the effects of all other volcanic clouds observed at Mauna Loa since observations were begun in 1958.
J. Geophys. Res., Green, Paper 3C0814

3770 Particles and aerosols
AEROSOL MEASUREMENTS AT FOUR BACKGROUND SITES
B. A. Bodhaine (Geophysical Monitoring for Climatic Change, Air Resources Laboratories, NOAA, Boulder, Colorado, 80303).

Atmospheric monitoring stations are operated at Barrow, Alaska; Mauna Loa, Hawaii; American Samoa; and South Pole by the Geophysical Monitoring for Climatic Change program to measure the characteristics of gaseous and aerosol species under background conditions. A nearly continuous record of light-scattering coefficient and condensation nuclei concentration measurements is available for Barrow since 1971, Mauna Loa since 1974, Samoa since 1977, and South Pole since 1974. The Barrow light-scattering data exhibit a strong annual cycle with a maximum in winter and spring (the Arctic haze), and a minimum in summer. The Barrow condensation nuclei data exhibit a strong semiannual cycle with a maximum coinciding with that of light scattering and an additional maximum about August. The Mauna Loa light-scattering data show a strong annual cycle with a maximum in April or May caused by long-range transport of Asian desert dust. The Mauna Loa condensation nuclei data show no significant annual cycle. The Samoa light-scattering and condensation nuclei data are representative of a clean marine atmosphere and exhibit no significant annual or diurnal cycle. The South Pole light-scattering data show a complicated annual cycle with a maximum in the austral summer and a minimum about April. The austral winter is dominated by events most likely caused by the transport of sea salt in the troposphere from the coastal regions to the interior of the Antarctic continent. The South Pole condensation nuclei data show a repeatable annual cycle with a maximum in the austral summer and a minimum in the austral winter. Linear least squares trend analyses show no significant long-term trend compared to the standard error about the regression line at any station.
J. Geophys. Res., Green, Paper 3C0762

3790 Instruments and techniques
RAINDROP-SIZE DISTRIBUTIONS AND VERTICAL AIR MOTIONS AS INFERRED FROM ZENITH POINTING DOPPLER RADAR WITH THE RONSARD SYSTEM
D. Hauser and P. Amayenc (CNET-CNRS, Centre de Recherches en Physique de l'Environnement Terrestre et Planétaire, 38-40 rue du Général Leclerc, 92131 Issy-les-Moulineaux, France)

This paper deals with results of raindrop-size distributions and vertical air motions aloft from vertical incidence Doppler spectra gathered with one radar of the RONSARD system. Results are obtained in two different cases of stratiform rain by using a new method recently proposed by the authors, based on the hypothesis of exponentially shaped raindrop-size distributions. It is found that this method produces values of the rainfall parameters with higher time and space variability than those depicted from the well-known Rogers approach. Moreover the rainfall bulk parameters are accurately connected only by means of three parameters relationships. For one case, the results are compared to in situ measurements of raindrop-size distributions aboard an aircraft and indicate that the proposed method provides with satisfying estimates of the precipitating water content and of the median volume diameter of raindrops. (Drop-size distributions, stratiform rain, Doppler radar).
Rad. Sci., Paper 3S0855

3790 Instruments and techniques
A GENERALIZED ANALYSIS OF DUAL-POLARIZATION RADAR MEASUREMENTS OF RAIN
D. P. Stapor (1101 Vista Oaks West, Palm Bay, Fla., USA, 32905) T. Pratt

In the study of meteorological phenomena by radar, it has been shown that dual-polarization radar measurements can yield useful data about precipitation structures within the radar beam. The techniques available for dual-polarized radar measurement are: differential reflectivity (Z_{DR}), linear depolarization ratio (LDR), and circular depolarization ratio (CDR). This paper presents a theoretical analysis of backscattering from a volume filled with raindrops using Rayleigh scattering theory. A generalized radar equation is developed in matrix form and the dependence of backscatter measurements in terms of a rainstorm model including raindrop shape, size and canting angle is examined. Calculated results which show the dependence of Z_{DR} on beam elevation angle and polarization angle are presented. Some results for LDR and CDR are presented showing how these quantities depend on raindrop parameters. (Dual-polarization radar, Rayleigh scattering, Rain)
Rad. Sci., Paper 3S0382

3799 General (Ozone Changes)
STRATOSPHERIC OZONE CHANGES AND TRANSPORTS DURING THE FIRST YEAR OF SBUV OBSERVATIONS NOVEMBER 1978 - OCTOBER 1979
S. M. Nagatani and A. J. Miller (NMC, Climate Analysis Center, Washington, D.C. 20233)

Synoptic analyses of Solar Backscattered Ultraviolet (SBUV) ozone data have been performed on a daily basis for the first year of Nimbus 7 operation, November 1978 through October 1979 at the standard pressure levels, 30-, 10-, 5-, 2-, 1- and 0.4-mb. By combining these data with the daily NMC meteorological analyses of temperature and geostrophic wind at the same levels we are able to examine elements of the ozone-temperature relationship as well as the horizontal eddy transports. In particular, the existance of an upper stratospheric high latitude ozone minimum in winter is discussed with the eddy fluxes found to play a significant role in this feature, mainly associated with stratospheric warming pulses. At the same time, monthly average quantities are examined and standing eddy components related.
J. Geophys. Res., Green, Paper 3C0779

Oceanography

4713 Circulation (Equatorial Pacific)
INTERANNUAL VARIABILITY OF THE EQUATORIAL PACIFIC — REVISITED
A. J. Busalacchi (Goddard Laboratory for Atmospheric Sciences, NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771), K. Takeuchi and J. J. O'Brien

A linear numerical model forced by monthly ship-board wind estimates used to study the interannual response of the tropical Pacific Ocean for 1961-1970 (Busalacchi and O'Brien, 1981) is extended through December, 1978. The additional eight years include the 1972 and 1976 Los Ninos and the aborted event of 1975. Model pycnocline variations at several locations are compared with observed sea level fluctuations. El Nino events are depicted as periods when the pycnocline is persistently deep along the eastern boundary. Remotely forced equatorial Kelvin waves are responsible for this response. The character of each simulated El Nino is strongly dependent on the relation between zonal wind stress changes in the western and central equatorial Pacific. There are important differences in the location and timing of the wind changes associated with each El Nino. During the 1970's the easterlies in the central equatorial Pacific had more of an active role in the evolution of El Nino than in the previous decade. In the western tropical Pacific a rapid shoaling of the pycnocline during each El Nino is caused by westward-propagating Rossby waves. Interannual pycnocline displacements in the central equatorial Pacific are determined by the superposition of Kelvin waves excited to the west and first horizontal mode Rossby waves generated to the east. (El Nino, remote forcing, equatorial waves)
J. Geophys. Res., Green, Paper 3C0776

4730 Internal Waves
TIDAL PHASE OF INTERNAL-WAVE GENERATION
C. Sawyer
NOAA, ERL, Pacific Marine Environmental Laboratory
Seattle, Washington 98105
Presently working at the High Altitude Observatory
Boulder, Colorado 80307

The tidal phase at which ocean internal waves are generated is examined using two sets of data. The first data set, consisting of 21 time series of internal-wave packets located with respect to the continental shelf edge on satellite images, clearly indicates generation near flood tide. Observed location of wave packet confirms the expectation based on theory that internal-wave generation occurs at the shelf edge. Wave speed is determined from separation of packet pairs presumed to be generated at successive tides. This speed, with distance of the nearest packet from the shelf edge, determines the time of generation. Comparison to predicted tidal phase shows that all estimated generation times are within 3.2 hours of flood, and only one of the 21 values is closer to ebb than to flood. The mean value of generation time relative to maximum flood is -0.2 hours and the median value is -0.1 hour. The images cover all phases of the tidal cycle, and the result appears to be representative for shelf generation.

In the second data set, observations of thermal oscillations shoreward of a sill can be modelled either as generated shortly after ebb tide on the seaward side of the sill, or slightly before flood, on the shoreward side. The absence in both sets of observations of evidence of internal waves over the sill or seaward of the sill, points to flood generation at the sill as well as at the shelf. (Internal waves, tidal generation, satellite imagery).
J. Geophys. Res., Green, Paper 2C1788

Particles and Fields— Ionosphere

5530 High-latitude ionospheric currents
HIGH-LATITUDE IONOSPHERIC IRREGULARITIES: A REVIEW OF RECENT RADAR RESULTS
C. Hanuise (L.S.E.E.T., La Giponne, Bd des Armaris, 83100 Toulon, France)

Ionospheric small-scale irregularities are commonly detected with radar systems in both E and F regions from sub-auroral latitudes to the polar cap. In the E region, numerous observations performed at frequencies from HF to UHF have led to an understanding of the main features of the generating plasma instabilities. On the other hand, F region irregularities can only be detected with HF radars due to the aspect sensitivity of the echoes and the ionospheric refraction at these frequencies. Doppler studies have been performed only recently but have already shown that several well-known plasma instability mechanisms can explain the observations. We review in this work the radar observations of these various natural irregularities with emphasis on the recent results and their implications for the theories of their generating mechanisms. (High-latitude ionosphere, plasma instabilities, ionospheric irregularities).
Rad. Sci., Paper 3S0635

5540 Ion densities and temperatures
DIRECT MEASUREMENTS OF ION COMPOSITION WITH EISCAT IN THE HIGH LATITUDE F1 REGION
C. Lathuillère (Centre d'Etudes des Phénomènes Aléatoires et Géophysiques, BP 46, 38402 Saint-Martin-d'Hères, France), G. Lejeune, W. Kofman

We present a method for obtaining O^+ relative abundance directly from the autocorrelation functions measured by EISCAT : no assumption is made on the temperatures. Results of O^+ relative abundance and temperatures obtained simultaneously are shown for 20 hours period on May 9, 1982 and the time variations of O^+ relative abundance are compared to previous work.
Rad. Sci., Paper 3S0611

5560 Particle precipitation
ELECTRON ENERGY DEPOSITION IN THE MIDDLE ATMOSPHERE
A. L. Vampola (Space Sciences Laboratory, The Aerospace Corporation, P.O. Box 92957, Los Angeles, CA, 90009), and D. J. Gorney

Spectra of locally precipitating 36 to 317 keV electrons observed by the S3-2 satellite are used to calculate energy deposition profiles as a function of altitude, latitude, and longitude. In the 70-90 km altitude, midlatitude ionization due to these electrons can be comparable to that due to direct solar H Lyman α. Maximum average precipitation rates in the South Atlantic Anomaly are on the order of 10^{-2} erg (per cm²-sec) with a spectrum of the form:

$$j(E) = 1.34 \times 10^5 E^{-2.27} \text{ (keV)}$$

Southern hemisphere precipitation dominates northern for $1.1 < L < 6$ except for regions of low local surface field in the north. Above L = 6, local time effects dominate; i.e., longitudinal effects due to the asymmetric magnetic field which are strong features below L = 6 disappear and are replaced by high- latitude precipitation events which are local-time features. (electron precipitation, d-region, atmospheric ionization)
J. Geophys. Res., Blue, Paper 3A0773

5560 Particle Precipitation
STUDIES OF SPORADIC E (Es) ASSOCIATED WITH THE MAIN IONOSPHERIC TROUGH
A.S. Rodger, C. Morrell and J.R. Dudeney (British Antarctic Survey, Madingley Road, Cambridge, CB3 0ET, UK)

The occurrence of sporadic E (Es) under the main F-region trough has been established using ionograms from a vertical incidence ionosonde at Halley Bay, Antarctica (76°S, 27°W; L = 4.2), a site well suited for such studies as the trough can be seen under a wide range of magnetic conditions and local times. Analysis shows that Es is very frequently observed under both the equatorward and poleward edges of the trough, as well as poleward of it. Before magnetic midnight, Es layers with semi-thickness similar to those of the normal E layer are most common. This is in marked contrast to the layers seen after magnetic midnight which usually show the characteristics of thin Es layers. Additional information on the morphology and dynamics of Es layers associated with the main trough has been provided by detailed study of individual events using data from the British Antarctic Survey's Advanced Ionospheric Sounder recently deployed at Halley Bay. A possible explanation of the observed change in the Es-layer characteristics at about magnetic midnight is related to differences in the type and spectra of the precipitating particles. The effects of transport processes in the E-region are also considered as a possible cause. It is shown that the redistribution of ionisation by the convection electric field may be important. (Es layers, main ionospheric trough).
Rad. Sci., Paper 3S0613

5563 Plasma motion, convection, or circulation
EARLY MITHRAS RESULTS: THE ELECTRIC-FIELD RESPONSE TO SUBSTORMS
O. de la Beaujardière (Radio Physics Laboratory, SRI International, Menlo Park, California 94025), J. Holt and E. Nielsen

The MITHRAS data base offers a unique opportunity to observe simultaneously the auroral-zone ion-convection pattern with three radars, widely separated in longitude. We attempt to separate local-time versus universal-time effects in a study of the electric-field signature associated with substorms. Preliminary results indicate that this signature is similar at a given local time, regardless of the longitude of the station. In the dawn and dusk sectors, the electric field is intensified, whereas around noon and midnight, the electric field appears to reverse during a substorm. The potential drop across the polar cap can be estimated from the potential across the auroral oval. The radar data agree well with the relationship found by Reiff and coworkers between the solar wind energy parameter ε, and the cross tail potential. (Electric field, convection, substorm, incoherent scatter.)
Rad. Sci., Paper 3S0634

5563 Plasma Convection
RADIO STUDIES OF THE MAIN F-REGION TROUGH IN ANTARCTICA
J.R. Dudeney, A.S. Rodger and M.J. Jarvis (British Antarctic Survey, Madingley Road, Cambridge, CB3 0ET, England, UK.)

Case studies of the equatorward movement of the main F-region trough are presented, using data recorded by a digital ionospheric sounder located at Halley Bay (76°S, 27°W; Λ = 61.8, L = 4.2). Three events were chosen to give a range of magnetic conditions and local times. Comparison of the results, projected into the equatorial plane, with theoretical predictions of the simple 'tear-drop' model of the plasmapause, show remarkably good agreement for the two occasions when the level of magnetic activity remained approximately constant over the observing period. Consequently, estimates of the strength of the dawn-dusk convection electric field in the magnetosphere have been made. However, magnetic activity changed during the course of the other event and the comparison gave poor results. The main F-region trough results are also compared with the predictions of contemporary empirical equations which express the invariant latitude of the trough minimum as a function of local time and magnetic index, Kp, based on global satellite surveys. It is shown that some of these equations adequately accounts for the observed equatorward motion of the trough for these three cases. In particular, they contain insufficient allowance for the observed strong dependence of equatorward velocity upon magnetic activity. Some suggestions upon possible improvements to the empirical models are made which, if implemented, would be of great value for improving the reliability of predictions for high frequency, trans-auroral radio wave communications. (Dynamics, main ionospheric trough, observations, models).
Rad. Sci., Paper 3S0610

Particles and Fields— Magnetosphere

5720 Interactions between solar wind and magnetosphere
ENERGY FLOW AND DYNAMICAL COUPLING IN THE SOLAR WIND-MAGNETOSPHERE-IONOSPHERE SYSTEM
S.-I. Akasofu (Geophysical Institute, University of Alaska, Fairbanks, Alaska, 99701)

The solar wind-magnetosphere-ionosphere system is described in a simplest way in terms of a directly driven system powered by the solar wind-magnetosphere dynamo. An accurate distribution of the resulting Pedersen and Hall currents in the ionosphere, together with the corresponding electric potential pattern and the Joule heat production rate, is also presented. Field-aligned currents related to the ionosphere currents introduce a considerable complexity to this simple view by generating a potential drop along the geomagnetic field lines and thus providing auroral phenomena. It is shown also that the geometry of the open field line region, namely the polar cap, varies drastically as the Bz component of the interplanetary magnetic field becomes positive. Therefore, one must be cautious organizing and analyzing data from the highest latitude region. (magnetosphere-ionosphere coupling).
Rad. Sci., Paper 3S0758

5755 Plasma Instabilities
TERRESTRIAL VS JOVIAN VLF CHORUS; A COMPARATIVE STUDY
U. S. Inan (Space, Telecommunications and Radioscience Laboratory, Stanford University, Stanford, CA 94305), R. A. Helliwell and W. S. Kurth

The relevant parameters of the magnetospheres of Jupiter and Earth are studied from the point of view of wave-particle resonant interactions that are believed to be responsible for the generation of VLF chorus emissions observed on Voyager-1. Using existing models of the cold and energetic plasma distributions in the Jovian magnetosphere, expressions for the wave-particle interaction length (L_I) and the nonlinearity parameter (ρ) are derived. Values of these parameters are compared with those computed for the Earth's magnetosphere. It is found that the typical interaction lengths are at least 2-5 times larger in the Jovian than in the Terrestrial magnetosphere. Also, the wave intensity necessary to reach the threshold of nonlinearity in the Jovian magnetosphere was found to be up to 5-100 times lower. The Voyager-1 measurements show, however, that the inferred wave magnetic field intensities of the Jovian chorus are in the range of reported intensities for Terrestrial chorus. This is attributed to the fact that the fluxes of few keV resonant particles found in the Jovian magnetosphere were typically two orders of magnitude higher. By the same token, it is predicted that the temporal growth rates of Jovian chorus bursts should be typically higher than Terrestrial ones. Growth rate measurements on Voyager-1 broadband wave data are used to confirm this hypothesis. (Jovian chorus, growth rate, interaction length)
J. Geophys. Res., Blue, Paper 3A0794

5770 (Short Period Magnetic Variations)
SATELLITE OBSERVATIONS OF PI 2 ACTIVITY AT SYNCHRONOUS ORBIT
T. Sakurai (Department of Engineering, Aeronautics and Space Sciences, Tokai University, Hiratsuka, 259-12 JAPAN), R.L. McPherron (Department of Earth and Space Sciences, and Institute of Geophysics and Planetary Science University of California, Los Angeles, CA 90024)

Pi 2 magnetic pulsations are frequently observed at synchronous orbit by the UCLA fluxgate magnetometer on ATS-6. Events that occurred in September 1974 have been studied using digital power spectra and coherency analysis to determine wave characteristics. From examination of wave form and spectral analysis, these Pi 2 events can be divided into three types. The first is a superposition of a 100-second oscillation and a large-amplitude, higher-frequency Pi 1 activity. The second is a 100-second wave unaccompanied by Pi 1. Both types have a significant compressional component. The third is a pure transverse wave in the azimuthal component. The pure transverse waves are quite rare, while the compressional waves occur during almost every substorm. In general, if the satellite is in the local time sector 19-03 LT, a Pi 2 burst accompanies every onset. In addition, onsets at the satellite are associated with ground Pi 2 bursts. The peak occurrence time of the satellite Pi 2 is 2100 LT. An examination of Pi 2 polarization at the satellite suggests that a polarization reversal occurs around midnight during quiet magnetic conditions ($Kp \leq 3+$) left-handed premidnight and right-handed postmidnight. This result is similar to that obtained from ground-based studies at stations equatorward of the auroral electrojet. The initial perturbation in the azimuthal component of a Pi 2 event is in the same sense as the perturbations caused by substorm-associated, field-aligned currents, positive (eastward) premidnight, negative (westward) postmidnight. This observation indicates that there may be a very close association between their causative mechanisms.
J. Geophys. Res., Blue, Paper 3A0847

5780 Wave Propagation
OCCURRENCE PROPERTIES OF DUCTED WHISTLER-MODE SIGNALS FROM THE NEW VLF TRANSMITTER AT SIPLE STATION, ANTARCTICA
D. L. Carpenter (Space, Telecommunications and Radioscience Lab, Stanford University, Stanford, CA 94305), Z. T. Bao

A new VLF transmitter called Jupiter was installed at Siple Station, Antarctica (L ~ 4.3) in 1979. A study had been made of the occurrence properties of magnetospheric signals from the transmitter detected at the conjugate station, Roberval, Canada and in the two-hop mode at Siple in 1980. The diurnal variation of the signals exhibited the previously noted major activity peak near dawn and a secondary peak near dusk. The former is believed to be due to a corresponding peak in resonant particle fluxes within the outer plasmasphere, and the latter to destabilization of energetic particles that locally penetrated the evening bulge of the plasmasphere. The propagation paths followed by the better defined 2-4 kHz Siple signals had equatorial radii in the range $4 < L < 4.75$. This region maps at 100 km altitude to a north-south range of approximately ±150 km, centered on the latitude of Siple. The east-west range is believed to have been of comparable size. This concentration of signal paths is attributed to the effects of an injected-wave power threshold for fast temporal wave growth in the magnetosphere, combined with spacial variation in ionospheric illumination by the transmitter. Also important was a concentration of operator-selected transmitter frequencies below 4 kHz, which permitted ducted propagation (i.e., $f < f_{Heq}/2$, where f_{Heq} is the equatorial gyrofrequency) along field lines whose ionospheric projections were nearly overhead at ~100 km altitude. The data are consistent with the existence of a relatively narrow north-south separation of ~100 km or less between the ionospheric point of wave injection and the field lines of the duct itself. The Siple transmitter has been able to induce magnetospheric wave growth and triggered emissions over the range $0.2 < f/f_{Heq} < 0.5$. These results differ from the reported concentration at $f/f_{Heq} \sim 0.5$ of discrete-emission triggering by whistlers and by certain VLF transmitters. Enhanced Siple signal activity at ground stations has resulted from increases in transmitter power, a notable change from 1978 to 1980 being in the 2-3 kHz range, where Jupiter realized its largest (~10 dB) power advantage over Zeus. (VLF wave injection, coherent wave growth).
J. Geophys. Res., Blue, Paper 3A0688

5780 Wave propagation
OBSERVATIONAL EVIDENCE OF Z AND L-O MODE WAVES AS THE ORIGIN OF AURORAL KILOMETRIC RADIATION FROM THE JIKIKEN (EXOS-B) SATELLITE
H. Oya (Geophysical Institute, Tohoku University, Sendai 980, JAPAN), A. Morioka

The Jikiken satellite which had an initial perigee and apogee of 250 km and 30,050 km, respectively, and an orbit inclination of -31°, passed through critical regions, where auroral kilometric radiation (AKR) spectra were obtained on at least five occasions during a period from January 31, 1979, to June 21, 1980. On all of these occasions, the AKR spectra reveal cutoff phenomena at the local Z-cutoff frequency, indicating a continuation of the spectra from the high frequency side down to the Z mode wave frequency range and crossing over the local X-cutoff frequency rather than being cutoff at that frequency. Thus when the observations are made near the low latitude portion of the source region, the AKR waves generate spectra that continuously cover the frequency range corresponding to Z-mode and L-O mode waves. We argue that the most plausible mechanism that gives a consistent interpretation to this spectral characteristics is the mode conversion theory. In other words, the plasma waves that are generated in the hybrid mode in the source regions are converted into the Z-mode waves that propagate toward dense plasma regions where the wave frequency coincides with the local plasma frequency and where part of their energy is transferred to waves of the L-O mode that can escape towards outer space. By use of the propagation characteristics of Z-mode waves, this conversion mechanism also gives a self-consistent interpretation of previously presented evidence reported as the cutoff of AKR near the local electron cyclotron frequency. There is no conflict between the conversion mechanism for AKR generation and the previous polarization observations carried out by the Voyager spacecrafts, because of a possible ambiguity in the location of the source region. (Auroral kilometric radiation, satellite observation, mode conversion, L-O mode).
J. Geophys. Res., Blue, Paper 3A0586

5799 Plasma Motion (Expansion into vacuum)
THE EXPANSION OF A PLASMA INTO A VACUUM - BASIC PHENOMENA AND PROCESSES AND APPLICATIONS TO SPACE PLASMA PHYSICS
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In this paper we call attention to basic phenomena and physical processes involved in the expansion of a plasma into a vacuum, or the expansion of a plasma into a more tenuous plasma; in particular, the fact that upon the expansion, ions are accelerated and reach energies well above their thermal energy. Also, in the process of the expansion a rarefaction wave propagates into the ambient plasma, an ion front moves into the expansion volume, and discontinuities in plasma parameters occur. We discuss the physical processes which cause the above phenomena and point towards their possible application for the case of the distribution of ions and electrons (hence, plasma potential and electric fields) in the wake region behind artificial and natural obstacles moving supersonically in a rarefied space plasma. To illustrate this, some in-situ results are re-examined. Directions for future work in this area via the utilization of the Space Shuttle and laboratory work are also mentioned.
Rev. Geophys. Space Phys., Paper 3R0866

Physical Properties of Rocks

6110 elasticity, fracture and flow
SURFACE DEFORMATION ASSOCIATED WITH A DIPPING HYDROFRACTURE
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Crustal deformation associated with hydrofracture is modelled by a dipping rectangular dislocation beneath the surface of an elastic half-space. The Burger's vector is taken normal to the rectangle surface. Analytical expressions for vertical displacements are obtained from integration of Volterra's equation using Mindlin's point force solutions for the elastic half-space. To the limits of 0° and 90° dip, the results agree with those obtained by Maruyama (1964) for Poisson's ratio 0.25. Expressions for arbitrary Poisson's ratio are given. For elongate dislocations the displacement field agrees with curves given by Pollard and Holzhausen (1979) for two-dimensional, near surface fractures at various dips. At dip = 0°, a deep square dislocation gives displacements indistinguishable from those of Sun's (1969) model of a horizontal, penny shaped crack beneath the surface of an elastic half-space. Modifying his results for shallow depths shows that they correspond to a dislocation of semi-elliptical cross-section with the surface displacement field asymptotically approaching a semi-elliptical shape as depth decreases to zero. Similarly the surface displacement field of the square dislocation approaches that of its rectangular cross-section. Nonlinear inversions of surface tilt fields, associated with hydrofracture of deep boreholes, gives estimates of fracture geometry, position and orientation along with their uncertainties. Two examples are presented, one of a near horizontal and one of a near vertical fracture. (dislocation, deformation, hydrofracture)
J. Geophys. Res., Red, Paper 3B0587

6110 Elasticity, fracture, and flow
HYSTERESIS IN THE CLOSURE OF A NOMINALLY FLAT ROCK
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It is shown that when two nominally flat rock surfaces are placed together and subjected to a normal load, that the resulting closure closely follows a constitutive law predicted by theory. However, what is not predicted by theory is that the constitutive law exhibits hysteresis. The hysteresis is evidently produced by friction on parts of the surface where the contact is oblique to the load. This behavior, which should be shared by joints and other fractures in the upper part of the crust, suggests that the elastic properties of the near surface parts of the earth may be far more complex than previously thought. (Cracks, attenuation, elasticity).
J. Geophys. Res., Red, Paper 3B0811

Planetology

6519 (Atmospheres of Planets)
PHOTOCHEMICAL REACTIONS OF WATER AND CARBON MONOXIDE IN EARTH'S PRIMITIVE ATMOSPHERE
S. Chang (Extraterrestrial Research Division, NASA Ames Research Center, Moffett Field, California 94035) and A. Bar-Nun

The gas-phase photolysis of H_2O at 1849 Å in the presence of CO yields mainly CO_2 and H_2 and a variety of organic compounds, including C_1-C_3 hydrocarbons, alcohols, aldehydes, acetone, and acetic acid. The overall quantum yield for conversion of CO to organic compounds varies between 0.23 and 0.03 as a function of the CO abundance. These results indicate that even if primitive Earth's atmosphere initially contained no molecular hydrogen and contained carbon only in the form of CO or a mixture of CO and CO_2, the prebiotic environment would have become enriched with a variety of organic compounds produced by photochemical processes.
J. Geophys. Res., Green, Paper 3C0442

6530 Gross properties of planets (coordinates of features)
THE CONTROL NETWORKS OF TETHYS AND DIONE
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Control networks of Saturnian satellites of Tethys and Dione have been established photogrammetrically from pictures taken by the two Voyager spacecraft during their flybys. Coordinates of 110 points on Tethys and 126 points on Dione are listed; selected points are identified on U.S. Geological Survey maps of the satellites and many are identified by name. Measurements of these points were made on 6 pictures from Voyager 1 and 21 from Voyager 2 for Tethys and on 27 pictures from Voyager 1 and 1 from Voyager 2 for Dione. The longitude systems on the satellites have been defined by craters on their surfaces. The mean radii have been determined as 524 ± 5 km for Tethys and 559 ± 5 km for Dione. (Satellite radii, coordinate systems).
J. Geophys. Res., Red, Paper 3B0588

6530 Gross properties of planets (Radio - Astronomy)
DYNAMIC SPECTRUM OF SATURN KILOMETRIC RADIATION
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Dynamic spectra of Saturn kilometric radiation (SKR) obtained by the Voyager Planetary Radio Astronomy experiment have been searched for variations at a time scale longer than that of the arcs (about one hour). Two kinds of episodic changes of the shape of the dynamic spectrum can be distinguished : one is an overall long term change, lasting for one or several Saturn rotations ; the other is a modification of the dynamic spectrum from one rotation to the other, in the subsolar longitude range from about 270° to about 60°. Both correspond to a change in the shape of the intensity spectrum. The long term variation probably contains the so-called "Dione-gaps", together with similar and sometimes much longer events. The already discovered influence of strong solar wind activity corresponds to increases of the average intensity level of the emission, but not to changes in the shape of its spectrum. Both kind of episodic spectral variations are usually observed in "quiet" conditions, in particular when Saturn enters Jupiter's magnetic tail. These changes of the SKR spectrum are compared to those already observed in the terrestrial kilometric radiation. They could be due to complex propagation effects, temporary modifications of the emission beam or changes in the source altitude (Saturn radio-emission, spectral variations).
J. Geophys. Res., Blue, Paper 3A0585

Seismology

6950 (Seismic sources)
1979 HOMESTEAD VALLEY EARTHQUAKE SEQUENCE, CALIFORNIA: CONTROL OF AFTERSHOCKS AND POSTSEISMIC DEFORMATION
R. S. Stein and M. Lisowski (U.S. Geological Survey, Menlo Park, California 94025)

The coseismic slip and geometry of the 15 March 1979 Homestead Valley, California, earthquake sequence are well constrained by precise horizontal and vertical geodetic observations, and by data from a dense local seismic network. These observations indicate 0.52±.10 m of right-lateral slip and 0.17±.04 m of reverse slip on a buried vertical 6-km-long and 5-km-deep fault and yield a mean static stress drop of 7.2±1.3 MPa. The largest shock had M_L = 5.6. Observations of the ground rupture revealed up to 0.1 m of right-lateral slip on two mapped faults that are subparallel to the modeled seismic slip plane. In the 1.9 years since the earthquakes, geodetic network displacements indicate that an additional 60±10 mm of postseismic creep took place. The rate of postseismic shear strain (0.53±.13 μrad/yr) measured within a 30 x 30-km network centered on the principal events was anomalously high compared to its preearthquake value and the postseismic rate in the adjacent network. This transient cannot be explained by postseismic slip on the seismic fault but rather indicates that broadscale release of strain followed the earthquake sequence.

We have calculated the postearthquake stress field caused by the modeled coseismic slip. We assume that failure is promoted when the sum of the shear stress plus 0.75 times the fault-opening stress increases. Most aftershocks concentrate at points where the stresses are enhanced by 0.3 MPa (3 bars) or more; aftershocks are nearly absent where postearthquake stresses decrease by 0.3-0.3 MPa. Isolated off-fault clusters of aftershocks that locate at one fault length from the rupture plane are explainable by this hypothesis. We find that ground rupture and postseismic creep take place where near-surface stresses are calculated to increase within the preexisting fault zones. Patches that extend 4 km from both ends of the seismic fault exhibited neither aftershocks nor measurable postseismic creep. The sensitivity of aftershocks and ground rupture to changes in stress that are less than 5% of the earthquake stress drop demonstrates that the region around the earthquakes was within a few percent of its failure threshold before the main shocks. The preearthquake stress field and the stress required for failure must also have been nearly uniform. (preearthquake stress, seismic slip, geodetic measurement)
J. Geophys. Res., Red, Paper 3B0692

6970 Structure of the Crust and Upper Mantle
SEISMIC IMAGING OF THE ELBERTON GRANITE, INNER PIEDMONT, GEORGIA, USING COCORP SOUTHERN APPALACHIAN DATA
Donna K. Jurdy (Department of Geological Sciences, Northwestern University, Evanston, Illinois 60201), and Robert A. Phinney

Seismic imaging of the Elberton granite in the Georgia Inner Piedmont was undertaken to define its shape, and to determine its relation to the southern Appalachian thrust. The recent Consortium for Continental Reflection Profiling (COCORP) lines in the southern Appalachians suggest a major thrusting of a crystalline block over sediments, although the extent of this thrust is subject to interpretation. The fine-grained Elberton, of Late Devonian age, is the only major pluton crossed by the seismic traverse, and is not well-defined on the unmigrated Common Depth Point (CDP) seismic section. Migration by beam-forming reveals considerable variation in the direction of returning signal, and provides a clearer image of the laminated reflections, ubiquitous in the southern Appalachians, that have been interpreted as the equivalents of the Valley and Ridge sediments beneath an allochthonous sheet. The upper 5 km portions of the migrated and CDP sections lack events, probably because of the necessary stripping (mute) of a large-amplitude, early arrival from the seismic records before further processing. Filtering, and transformation of the data to the intercept-slowness domain to eliminate this interfering arrival are attempted to enhance the upper portion of the seismic sections. Although these approaches do not give a consistent picture of the shallow section, a pattern of scatterers located at depths of 2-3.5 km emerges; these may correlate with the base of the intrusive body. This identification of the granite base, along with the presence of the thrust-related reflectors beneath the pluton, suggests a pre-thrust emplacement of the granite. However, tectonic interpretations of the Inner Piedmont based on the Elberton granite are severely limited by assumptions: that the pluton age corresponds to time of cooling, that the pluton is not fed by a narrow (seismically elusive) feeder, and that the thrust has not been reactivated after emplacement of the intrusive body. If all these assumptions hold, then the Late Devonian age of the granite is the earliest possible time of thrusting. (Elberton granite, Appalachians, seismic imaging).
J. Geophys. Res., Red, Paper 3B0678

Solar Physics, Astrophysics, and Astronomy

7760 Radio Astronomy
THE SOURCE LOCATION OF CERTAIN JOVIAN DECAMETRIC RADIO EMISSIONS
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New evidence supporting the widely-accepted concept that certain of the Jovian decametric radio waves originate as northern-hemisphere extraordinary-mode cyclotron emissions (possibly from the Io flux tube) has been found. In the Voyager radio observations. Shortly after the closest approach to Jupiter, the wave signals received by Voyager 1 near 10 MHz exhibited cusps in the fringe pattern which is attributed to faraday rotation in the Io plasma torus. The diminished faraday rotation indicated by these cusps implies that the wave path had become perpendicular to the magnetic field in the torus. At nearly the same time, the wave polarization near 1 MHz (where faraday rotation is absent) exhibited a sudden reversal of its rotation sense, indicating that the wave path for these frequencies had also become perpendicular to the magnetic field at the spacecraft. For these two events, it was possible to project the wave paths back toward Jupiter and determine to some extent where the waves originated. It was found that the waves came from the northern hemisphere, at progressively lower altitudes with increasing frequency, and, if the source is assumed to be associated with an L = 6 field line, the emission seems to have occurred near the source cyclotron frequency somewhere in local midnight sector. This suggests that the source could be at the Io flux tube, since Io was, then also near local midnight. Since the polarization rotation sense was apparently right-handed with respect to the source magnetic field, the emitted wave mode must have been extraordinary. Furthermore, in order for the torus to produce a detectable faraday rotation, the emitted wave polarization must have been substantially non-circular and that would require a low plasma density near the source, much like that which occurs with auroral kilometric radiation at the Earth. (Jupiter, DAM Emissions, Faraday Rotation, Io plasma torus)
J. Geophys. Res., Blue, Paper 3A0654